Geophysical Research Abstracts
Vol. 12, EGU2010-3844, 2010
EGU General Assembly 2010

Strong impacts of the Gulf Stream anomalies on the large-scale atmospheric state

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Geological data and climate simulation models suggest that the North Atlantic Deep Water (NADW) that plays a critical role in the global thermohaline circulation may have gone through major fluctuations in the past, bringing with them major climatic anomalies around the basin. A future collapse of the NADW formation has been a concern, as theories and climate simulation models suggest freshening of the North Atlantic as a result of the carbon dioxide increase in the atmosphere. Meanwhile, attempts to find strong impacts of SST anomalies in the North Atlantic on the large-scale atmospheric state in the data and simulation experiments had not been very successful, casting some doubt on the extent to which the thermohaline circulation fluctuations affect the Northern Hemispheric climate.

In an attempt to find evidence of strong impacts of the SST anomalies along the Gulf Stream on the regional and Northern Hemispheric climates, we analyzed the ERA40 reanalysis data and Hadley Centre SST data with the near-surface baroclinicity as the key parameter that connects the extra-tropical SST anomalies with the large-scale atmospheric anomalies. We first calculated EOFs of the near-surface baroclinicity for the domain that covers the North Atlantic storm track for each month. We then compiled anomaly composites of the SST, net surface heat flux, and various atmospheric fields for the positive and negative phases of the first two EOFs for each month. We also compiled composites of the anomalies for the preceding and following months for the first two EOFs.

From the above diagnoses, we identified strong impacts of the SST anomalies in the vicinity of the Gulf Stream on the large-scale atmospheric state, mostly in cold months. The scale of the atmospheric anomalies generated is very large, on the order of 1000km to 10000km, spanning the entire hemisphere. Roughly speaking, there are two patterns of atmospheric anomalies. One is characterized by a meridional shift in the subtropical jet core and storm track, while the other is characterized by an enhancement or suppression of the jet and storm track. The anomalous surface temperature pattern that accompanies the events of a meridionally-shifted jet is the pattern found for the Arctic Oscillation. The SST anomalies found in the composites often show large values along the Gulf Stream, and appear to have a direct impact on the near-surface baroclinicity. Composited anomalies in the net surface heat flux and surface wind in the preceding months strongly suggest that the SST anomalies are not the direct product of the anomalous atmospheric forcing, and that the anomalous Gulf Stream is likely to be responsible for generating the major large-scale anomalies in the atmosphere. It implies that even larger SST anomalies in the vicinity of the Gulf Stream expected in the event of the NADW formation collapse will likely have dramatic impacts on the Northern Hemisphere.

We note, however, that major anomalies in the atmosphere is not necessarily guaranteed when there are large SST anomalies along the Gulf Stream. The atmosphere responds to the SST anomalies only when the near-surface baroclinicity is modified in such a way that the modified baroclinicity favors generation of the atmospheric response.